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Navigating expert skepticism and consumer distrust: Rethinking the barriers to vehicle-to-grid (V2G) in the Nordic region

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ABSTRACT

Vehicle-to-grid (V2G) refers to a technology that could help make the electricity grid more effective, reduce the cost of ownership of electric vehicles (EVs), and help integrate intermittent renewable energy sources. However, despite these advantages, implementation and even knowledge of the technology is not widespread. In order to explore why, we ask the question: what are the barriers that V2G currently faces? To provide an answer, the authors conducted 227 semi-structured interviews with transportation and electricity experts from 201 institutions across seventeen cities within a market currently experimenting with electric mobility and V2G, the Nordic region. Results show that there is an extensive range of barriers facing V2G, with experts suggesting in total 35 categories of barriers. While the literature espouses substantial benefits of V2G, the experts interviewed generally displayed skepticism of the benefits and necessity of V2G in the Nordics. We categorized the top nine discussed barriers into four clusters. These clusters focused on the experts' skepticism of the benefits of V2G, consumer acceptance, economic viability, and regulatory structure for V2G participation. We conclude the paper with policy implications and suggestions for future research.

1. Introduction

Electric vehicles (EVs) can offer benefits to the grid by providing their battery as a means of storage, a concept called vehicle-to-grid (V2G) (Kempton and Tomić, 2005b). V2G can provide several benefits to individuals and society, including improving grid efficiency, revenue from electricity market participation, and integration of renewable energy into the power system (Sovacool et al., 2017; Noel et al., 2017; Lund and Kempton, 2008; Niesten and Alkemade, 2016). Because of the vast benefits it may offer, V2G has garnered much attention in the academic literature, with a substantial amount of focus on its renewable energy integration, electricity market services and battery degradation. Despite the potential benefits that V2G could provide to a variety of actors as well as the recent academic focus on the technology, V2G has failed to make a substantive mark in the transport and electricity sectors, with only a few pilot projects currently in progress around the world (Sovacool et al., 2017).

While literally hundreds of papers have looked into the potential benefits that V2G could offer, only a few papers have explored the barriers that V2G has and will continue to face. Most recently Sovacool, Axsen and Kempton reviewed the current barriers that V2G and vehicle-grid integration (VGI) currently face, and found that the central barriers were communication, battery degradation, capital cost and consumer-based barriers (Sovacool et al., 2017). Similarly, Turton & Moura found that the key uncertainties of V2G were cost, communication, and consumer acceptance, as well as competing storage technologies and potential decrease of automobile use (Turton and Moura, 2008). Parsons et al. focused on consumer acceptance to V2G and found that users have a strong distaste particularly for signing V2G contracts requiring a certain amount of hours per week to be plugged in, as it impedes on their freedom to use the car (Parsons et al., 2014). Bailey and Axsen investigated consumer perceptions of controlled charging, and found that consumers favored the development of renewable energy, but were concerned about perceived loss of control as well as privacy concerns (Bailey and Axsen, 2015).

Here we endeavor to characterize the full set of barriers to vehicle-to-grid while utilizing a methodology previously unused in the V2G literature, expert interviews. Indeed, the experts both corroborated and contradicted some of the barriers that the previous literature has proposed as key to a V2G transition. In all, the experts presented a total of 35 categories of barriers for V2G. These barriers generally focused on endogenous barriers to the technology and were infused with skepticism with performance and value of V2G. We discuss the nine most commonly discussed barriers, which we in turn grouped into 4 clusters.

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2. Research methods

To explore the barriers of vehicle-to-grid technology, the authors relied primarily on original data collected through semi-structured research interviews. This methodology was applied on a regional context taking the five Nordic countries as place of study, since it is recognized that these countries have traditionally been at the forefront of pushing forward climate, energy and transport policy agendas emerging as leading nations in electric vehicle uptake (Norway and Sweden), or pioneers of wind energy (Denmark), geothermal energy (Iceland) and bioenergy (Finland) (IEA, 2016).

The implementation of semi-structured interviews allows the authors to have guidance and flexibility, by asking a set of fixed questions to them, create a conversational channel of information-gathering, allowing space for spontaneous responses that add depth and in some instances unforeseen narratives to the research (Harrell and Bradley, 2009). This semi-structured form of interviewing is suitable when the objective of the research is to understand complex elements and their intersection with perceptions, beliefs, and values (Yin, 2003). Lastly, the authors selected this research method as it allowed for novel and up-to-date data (at the time of the interview) which was not available in other formats, since official documents can take months or even years to be published.

The authors conducted 227 semi-structured interviews with participants from 201 institutions across 17 cities in the five countries of Denmark, Finland, Iceland, Norway and Sweden from September 2016 to May 2017. Those interviewed were selected to represent the diverse array of stakeholders involved with transport and energy technology, policy and practice, and included members of:

- National government ministries, agencies, and departments including the Ministry of Industries & Innovation (Iceland), Ministry of Environment and Energy (Sweden), Ministry of Finance (Finland), and Ministry of Taxation (Denmark):
- Local government ministries, agencies, and departments including the Akureyri Municipality (Iceland), City of Stockholm (Sweden), Aarhus Kommune (Denmark), City of Tampere (Finland), City of Oslo (Norway), and Trondheim Kommune (Norway);
- Regulatory authorities and bodies including the National Energy Authority (Iceland), Danish Transport Authority, Icelandic Transport Authority, Helsinki Regional Transport Authority (Finland) and Trafi (Finland);
- Universities and research institutes including the University of Iceland, Swedish Environmental Institute, DTU (Denmark), Aalborg University (Denmark), VTT Technical Research Centre (Finland), NTNU (Norway), and the Arctic University of Norway;
- Electricty industry players such as ON Energy (Iceland), E.ON (Sweden), Vattenfall (Sweden), Energinet (Denmark), DONG (Denmark), Fingrid (Finland), Elenia (Finland) and Statnett (Norway);
- Automobile manufacturers and dealerships including the BMW Group (Norway), Volvo (Sweden), Nissan Nordic (Finland), Volkswagen (Norway), and Renault (Denmark);
- Private sector companies including Siemens Mobility (Denmark), Nuvve (Denmark), Fortrum (Finland), Virta (Finland), Clever (Sweden), Nordpool, (Sweden), Norske Hydrogen (Norway), Microsoft (Norway) and Schneider Electric (Norway);
- Industry groups and civil society organizations such as Danske Elbil Alliance (Denmark), Finnish Petroleum and Biofuels Association, Tesla Club (Finland), Power Circle (Sweden) and the Norwegian Electric Vehicle Association.

Interviews lasted generally between thirty and ninety minutes and were conducted in English and in person (primarily) or else by phone. Generally, the interviews were conducted by either one or two of the authors. The participants were asked, among others, the question: "What are the barriers that vehicle-to-grid faces?". Additional fixed questions focused on the benefits and barriers of electric vehicles, benefits of V2G, as well as general transportation and electricity challenges, but the results of these are presented elsewhere (Noel et al., 2018; Sovacool et al., 2018a,b; Sovacool et al., 2018c). In the study, participants were not prompted for responses, talked on a personal level, and were permitted to answer as long or as detailed as they wished.

Of course, there are some downsides of employing semi-structured interviews as a methodology. First, the interviews are influenced by self-selection bias of the interviewees, as well as limited to those who spoke English. While English was only a minor issue for our interviews, we actively countered self-selection bias by inviting widely and deliberately using snowballing and contacts to gain interviews at institutions and focus areas that were missing. Secondly, though the interviews use a set of fixed questions, each interview is moderated by the preferences of the interviewers in terms of follow-up questions and unique perspectives. We countered this by revolving the interviewers in different teams for the first half of the interviews and daily meetings during the fieldwork to discuss findings and questions. Thirdly, the level of expertise and background of interviewees can influence the types of topics they discuss, as they may deem certain answers as common knowledge, and move onto more compelling subjects. Wherever the interviewers realized that the level of expertise would impact our findings, they used follow-up questions to counter this.

Each interview was recorded and after completion fully transcribed and analyzed inductively. These transcriptions were subsequently coded in NVIVO by one of the authors, following an inductive, grounded theory approach in order to reduce interpretative bias from the researchers discussed above. That is, the interviews were coded without *a priori* categories, and instead were coded based on the arguments presented in the interviews, and thereafter gathered into higher categories and themes. Each interview was also given a unique respondent number (which we refer to whenever presenting interview data), see Table 2, even though some of them contained two or three interviewees (to a total of 257 individuals). We sought to maintain validity by triangulating interviews internally (with each other) and externally (with peer reviewed literature, when relevant).

3. Results & discussion

In total there were 35 categories of barriers to V2G identified by the experts, as shown in Fig. 1. Of these 35, there were 9 barriers discussed most frequently being discussed by at least 10% of the experts, a threshold that has been used in other work on social acceptance and socio-technical change (see (Sovacool and Hess, 2017)). While there was no single barrier agreed by a majority of the experts as the most prominent V2G faced, many of the categories carried a similar theme. As a result we sorted these 9 most discussed barriers into four clusters based on similarity, as shown in Fig. 2. This analysis was also done in NVIVO, and it utilizes a Jaccard's coefficient of similarity (Jaccard, 1901), a metric for comparing shared similarity between two disparate data sets, implying a larger value has a larger share of coding similarity, i.e. the themes were more closely related.

Much of the discussion of focused on the expert's skepticism of the benefits V2G could provide, also pertaining to the economic efficacy of V2G, social barriers including consumer willingness, and technical barriers of whether the technology could be implemented. Overall, the barriers were generally infused with a cynicism of the proof of concept, and less about external barriers inhibiting the technology. We discuss each of the 9 barriers in the four meta-sections in greater detail below.

3.1. Cluster 1: preference, unnecessary, and uncertainty

By far the most common perceived barrier was that V2G could be outperformed by other technologies, as described by 28% of

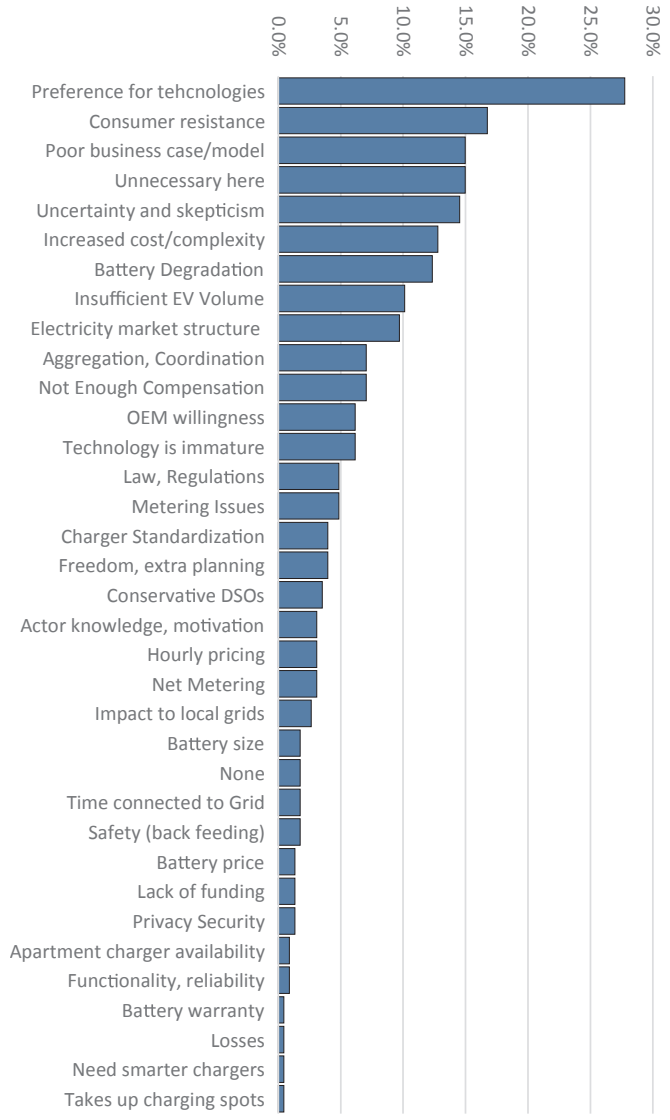

Fig. 1. Barriers to vehicle-to-grid identified by respondents.

respondents. The experts discussed 12 other technologies that would be preferable to V2G as shown in Fig. 3. In addition, this was highly correlated with two other barriers: that V2G was valuable but not needed here (15% of respondents), and conversely, that experts were either uncertain or skeptical of the benefits of V2G (also 15% of respondents). Much of the discussion of V2G was placed in the context of the fact that the Nordics have well developed grids with a variety of other storage options, namely hydroelectric power (IEA, 2016). For example, while R110 acknowledged that V2G has the capacity to provide several types of ancillary services to the grid, the respondent was skeptical that the additional costs of V2G would be outweighed by the benefits of a variety of alternative technologies:

> "*I'm not so optimistic about it, looked about from a vehicle-to-grid point of view is that we think we have cheaper and better alternatives and that's my simple reasoning … So I believe the vehicle-to-grid is a brilliant idea, I just think we have better ideas.*"

Hydropower was the most commonly discussed alternative to V2G, with it being explicitly discussed by 37% of the experts who discussed an alternative to V2G. Much of the comparisons between V2G and hydropower were framed in either technical sufficiency of hydropower or the low cost of already existing hydro in comparison to often perceived expensiveness of V2G. For instance, when asked about the potential role of V2G, R17 responded that its value would be limited as a result of the cheapness of existing hydropower:

> "*Very little, very little. It is much easier and cheaper to store the power in the reservoirs.*"

Similarly, R38 adds that hydropower in northern Sweden is significantly cheaper than V2G batteries:

> "*Yes, but I don't think we are quite there yet. It is very expensive, storage of a battery … There are huge dams up in northern Sweden which you can use to regulate. It is a much cheaper way to store energy and to keep the water before the turbines and let it out.*"

In addition to being cheap, existing hydro was also perceived as having several technical advantages over V2G. As R30 describes, while Sweden has EV research programs in place with the local utilities, V2G will not have a place in the electricity market due to the controllability of hydropower:

> "*I guess that won't be used in Sweden at the moment. Or hasn't got a market place for that. Because we have a very stable electricity system*

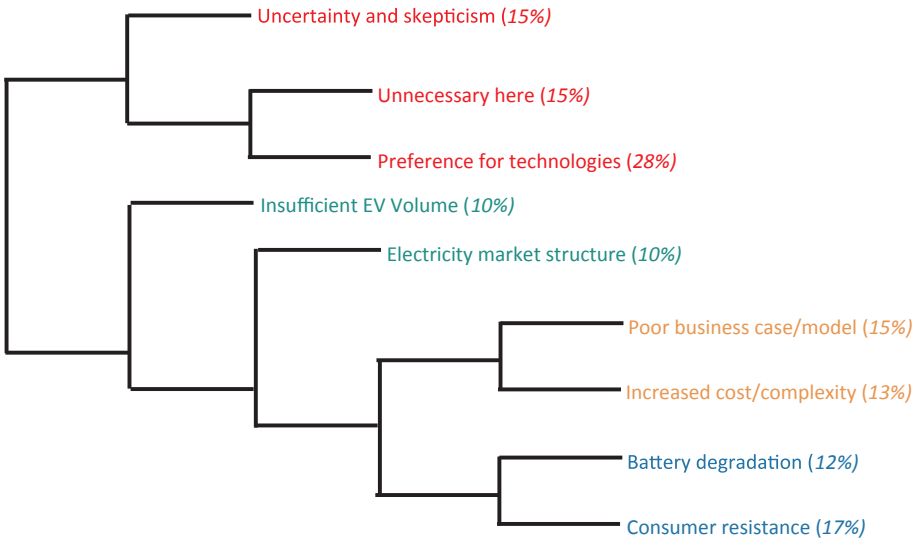

Fig. 2. Dendogram of Top 9 Most Common Barriers, Organized by Jaccard's Coefficient of Similarity, Colors denote Cluster groupings (*Italics represent Percent of Respondents Discussing Barrier*).

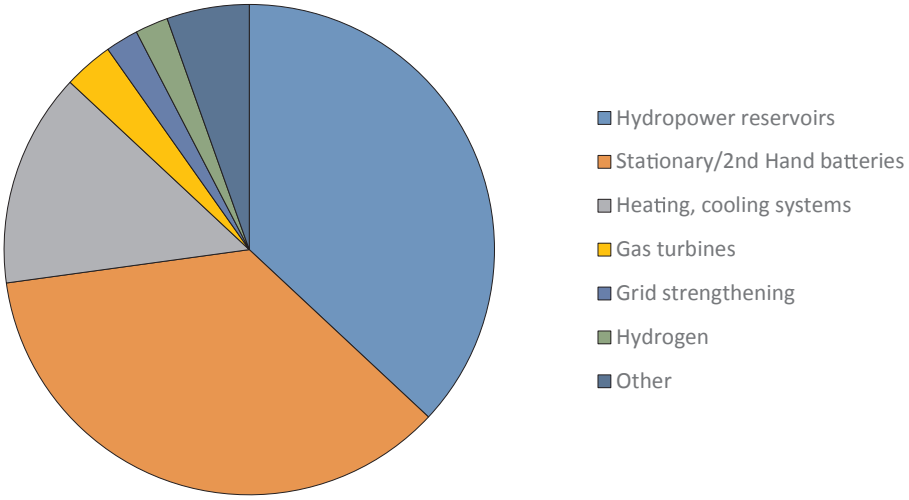

Fig. 3. Alternative technology preferred, as specified by respondents.

with controllable hydro at the top, or at the bottom. But it's a very controllable source of electricity, so I guess its not a major interest in Sweden. We have EV research programs together with the car industry and utilities, [so] no that's not a major issue here."

At the same time, R172 in Norway points out that V2G will have limited value across all the Nordics because of the longer timeframes required for storage to balance out renewable energy intermittency, which again would favor hydroelectric reservoirs:

"And a battery is not really feasible for long-term storage … That's where you need the big hydro plants. That's why Norway can really fit into this mix, when it comes to [a] political discussion."

Finally, in addition to being easy to control and better suited for long term storage, hydropower also was able to react nearly as fast as V2G, as R190 points out:

"*I don't see huge benefits simply because we already have so much capacity, you know we have hydroelectric power plants that can be turned on in fifteen seconds and they can go up to four megawatts in fifteen seconds in some of our plants … _*"

Of course, this discussion was most common in Norway, Sweden and Iceland, where their natural resources have benefitted their electricity system; but respondents in Denmark and Finland also alluded to hydropower advantages, as its local grid benefits are shared through the common power market, Nordpool. Thus, many experts believed that additional storage in general was not needed in the Nordics, and implying that the benefits of V2G within the region would be quite limited. Some of the experts clarified that V2G would be valuable in other regions, like southern Europe or the United States with increasing RES, but some others were skeptical of its inherent value regardless of location.

On the other hand, the next most common alternate technology was some form of stationary battery, which does not have the advantage of an existing legacy in the Nordics. 36% of experts who discussed using an alternative technology preferred stationary batteries as opposed to V2G. This category was split into two nearly equal subsections; secondhand EV batteries repurposed for storage capacity, and new purpose-built batteries. The surprisingly frequent discussion of secondhand batteries may be perhaps related to the other barriers listed below, such as consumer acceptance of using the battery while it is in the car still. Some of the experts also noted that with stationary batteries one can choose its location of placement, which is not always the case for V2G. And while hydropower was seen as having an economic advantage over EVs and V2G, stationary batteries were perceived to become substantially cheaper in the coming years, as a result of battery production for wide-scale EVs, as R50 notes:

"*However, I do believe that what will be more important is that as the vehicle industry increase the scale of battery production and the cost of batteries decrease, then, you will not use your battery in your car to stabilize your electricity grid at home, but you would rather buy another stationary battery.*"

In addition, stationary and secondhand batteries also have the advantage in that they can be aggregated into single locations, making the system substantially simpler than a network of V2G capable EVs, as R54 notes:

"*But it does feel now - I would say with a bit of perspective - that it's perhaps an unnecessarily complicated solution. That you could probably have the same function in a cheaper and simpler way by, for example, taking the used battery packs from electric vehicles and stacking them in one place, and using that as a battery-to-grid power source.*"

Finally, R135 argues that second-hand batteries would otherwise be wasted if not used for storage, considering that they would still have more than enough capacity for storage services, if not for driving use:

"*Let's say given that the safety and the performance is okay, I would think it's stupid to discard a battery system at 80% capacity left. You can just move it from the, let's say high duty use and have it in a milder application, to maybe, for example enable fast charging in areas where the power grid is weak.*"

Second-hand or purpose-built stationary batteries may have been in response to some of the other barriers discussed below (e.g., consumer acceptance and battery degradation). While certainly barriers like consumer acceptance would be lesser using stationary batteries, some of the central barriers that experts applied to V2G would be exacerbated by building two sets of batteries. To illustrate, many experts were skeptical of the business case of V2G due to the increased cost of the system and limited business case, but the cost would be even higher for stationary batteries, with the same business case. Thus, though secondhand or purpose-built stationary batteries may assuage certain barriers, they may face additional barriers as compared to V2G.

Finally, the third most common alternate technology was to utilize heating and cooling systems, by modulating electricity power delivered in order to provide ancillary services, or just as a means to store excess electricity for later use. While heating and cooling systems do not have the capacity of bidirectionality, as V2G would, many experts believed that bidirectionality was not necessary, and the benefits of V2G being

bidirectional were outweighed by the costs as compared to other, unidirectional technologies. Instead, as R125 describes, heating systems in Finland have three advantages over V2G; easier to operate, already exist, and large capacities:

"*So I guess that would be easier to control and of course heat storage is, we already have a lot of experience from that, Helsinki energy, Helen, called nowadays, they have a lot of district heating and they have a lot of district cooling as well, so they have like huge heat storages*."

Likewise, the same benefits can be applied to cooling systems, as R72 notes:

"*If you look at frequency you can have cooling technologies that can provide frequency, we've done some research projects that we put a measure for frequency and can react to its future, turn a freezer on and off, things like that can be turned on and off, as long as the compressor is not turned on and off 10 times in 2 minutes*."

Some of the experts were very optimistic about the capacity of heating systems. For example, R150 implied that the Nordics would only need to utilize their already existing heating systems as storage to integrate renewable electricity:

"*In all of the Nordic countries, where there are big heating district networks, we could use the surplus electricity as a heating source. So if we have problems with price differences and too much renewable electricity coming in, we can always dump it in the heating networks … If we begin to see fluctuations like that, the heating networks can be the balancing option for electricity*."

The remaining alternatives comprised less than 13% of technologies and were not brought up by many experts. Beyond the six technologies named in Fig. 2, the five categories of alternate technologies that comprised the "other" category included: controlling industrial demand, leveraging interconnections, automating nuclear or wind power production, and finally, power-to-gas. However, for each of these technologies, only one expert proposed using them over V2G.

3.2. Cluster 2: consumer resistance and battery degradation

Consumer resistance was the next most common concept, discussed by about 17% of experts. The consumer-based barriers were categorized into two subsections – either consumers would be unwilling to accept a third party to access their battery, or that the concept of V2G was too complex for the consumers to understand. Logically, the former was also connected to the concern that V2G would accelerate battery degradation, discussed by 12% of experts.

First, experts mentioned consumer unwillingness about twice as often as the complexity barrier, and much of the discussion centered on the proprietorial behavior of the consumers regarding their battery. Some experts went as far as describing allowing another party to use EVs for V2G as a type of vandalism (e.g., R122). V2G would encroach on the idea that the car is the last form of autonomy. In addition, given the central concerns of battery life and range for EVs, it is not surprising that consumers are wary of any action that could inhibit their battery. As R35 summarizes, consumers would not be willing to have anyone tamper with their batteries, given how afraid they are of reductions in battery life:

"*I would say they are not interested at all … They are very afraid of their batteries … But for every electric vehicle owners, they are, we have all kinds of discussion about battery life and how to improve it et cetera, et cetera. And then to tell them the electric company will play with your battery, no thank you*!"

Similarly, R43 added that consumers are justifiably skeptical of trusting utilities with, given the degradation of their battery, one of the most expensive possessions they would own:

"*You connect it to the most expensive [possession] you own. Then the battery is the most expensive part in the car, I'm not sure the consumer would trust whoever it is, perhaps the utility, trust that it's worth it, the degradation on the battery and so on*."

However, some experts, such as R131, misunderstood and overstated the impacts of battery degradation, especially compared to the current literature that states additional battery degradation from V2G participation would be minimal (Wang et al., 2016):

"*Right now, they are not used as storing electricity because nowadays batteries at car battery manufacturers only give a certain figure that you can only charge 10,000 times and then its dead*."

On the other hand, some experts believed that the battery degradation barrier would decrease over time as battery technology is expected to improve, as R35 later clarified, but also stating consumer acceptance would still hamper development of V2G for the next several years. The concern of V2G impacts on battery life is exacerbated by the fact that consumers view this third party intrusion as a limitation on the primary purpose of the vehicle, which is to drive, as R209 describes:

"*But then it opens a lot of other issues for people that actually own that battery, and own it not as a battery but as part of a car that they want to drive. So, there are all these issues around the psychology of giving somebody access to your battery. That you don't have it to store electricity, but to drive a car*."

This is not to say that all experts believed that consumers would prohibit access to their battery, but instead, experts believed that consumers would need to be sold on the value of V2G before third parties "vandalize" their batteries. For example, R125 acknowledges a small portion of consumers would participate in V2G for environmental reasons, but the wider majority would need to be sold on the business model before participation:

"*First they have to be sold with the electric vehicles and then they have to be sold on the business about participating on the regulation market or whatever, consumers won't do anything unless they somehow feel they are profiting from it. Some people of course are willing to participate just by if you tell them that this will save the planet then they will do it, but that's not the majority, the majority is looking for the price and the benefit for them*."

But at the same time, understanding how V2G works, and subsequent other topics, like frequency regulation and the markets behind that, can be overly complex for consumers to understand well enough to encourage participation. Indeed, even understanding the basic concept of V2G may pose a serious challenge to the consumer, as R219 found in their experience discussing V2G with consumers:

"*In one other project, we try to ask people about this vehicle to grid, and it was really difficult to get people to give answers because the whole concept was so weird to them … So, it was really difficult for people to visualize how it would work*."

Similarly, R84 described that the central challenge to V2G is for consumers to understand the concept, and expected consumers to react negatively with confusion:

"*What the hell is V2G that doesn't suck my vehicles dry so I can drive. Or what is going on. Why is my neighbor getting my power. How do you explain why the electric power should be able to leave your vehicles and ensure people that its under control and won't leave you empty vehicle every morning. So user education perhaps*."

At the same time, it is not necessary for the consumer to understand every detail of V2G technology, or the related complexity of electricity markets. R105, when discussing V2G, made an analogy between simplifying V2G and not fully understanding the complexities of air travel as a consumer:

"*So I think that when we talk about general public, simplify, simplify, simplify. Don't worry about it, there are so many things I don't understand, I just blindly go in it. Like a plane. I have no idea how it stays up in the air, but I fly*."

Thus, as long as consumers understand and opt into the basic conceptualization of V2G, as they do for airplane travel, then the complexity of V2G need not be a barrier. As such, many of the experts focused on simplifying V2G into basic terms and allowing consumers to easily understand and interact with V2G. Illustratively, R45 believed that the success of V2G is dependent on the complexity of the interface:

"*It's too new for them. And that's why I think it's a lot of question of technicality and how you create the interface and making it easy for people to understand*."

Finally, R63 recommended keeping V2G simple enough for non-engineers to comprehend, recommending reducing V2G into three easy selling points to prevent "scaring" consumers away:

"*No, I mean, if the company puts it really simple for the customers, because if they get a long list of technical terms, I think, - I mean, I am an engineer, I like that - but most people don't. I think that will scare them. So, it should be like, three easy selling points. That you can't say no to basically. If that is possible*."

However, for every two experts saying that consumer acceptance and mental barriers were an impediment for V2G, there was one expert who explicitly said it was not an impediment. Many of these experts agreed with the sentiments discussed above, like complexity of the system and acceptance to use the battery, but also believed that these barriers would be nullified by user experience and assumed future simplification of user interfaces, as well as information regarding the limited impacts to battery degradation.

3.3. Cluster 3: poor business case and cost & complexity

Thirdly, 15% of respondents suggested that the lack of a business case or business model was the primary barrier to V2G. Generally, the respondents characterized the lack of business cases as having two root causes: either a lack of substantive economic benefits, and/or fundamental barriers to the development of a scalable business model. Inherent in the perceived business case formation was the expert's perceptions of the increased cost and complexity of increasing the capacity of an EV to make it V2G capable, of which 13% of respondents discussed. Likewise, this increased cost of V2G was often compared to the availability of cheaper alternatives. For example, R114 believed that V2G would not have a business case because of low electricity prices and competing technologies, particularly within the DSO perspective:

"*I cannot see the opposite way around, [and] that the battery delivers electricity to the grid. That would not be easy for me to understand … I can't see the business case, because it could perhaps solve problems in the low voltage grid, but the people that run this low voltages grid, would say it's better to just make a stronger cable*."

As a result of the perceived cheap competitors to V2G, many experts were skeptical that the additional cost of V2G would be warranted. For example, R76 was skeptical that the increased cost of bidirectionality, as compared to simple controlled charging, would have a valid business case:

"*I'm hesitant to believe that the additional benefits of going to vehicle to grid as opposed to just stopping and charging can offset those costs. So that is one thing.*"

Connecting with the region inundation of cheap affordable hydro, R31 added that there was no business case for V2G in Sweden, but acknowledged that there may be more economic value in other regions:

"*Yes, so that problem doesn't exist here. You can't make a business case around that so easily. In California and in other parts of the US, you have a frequency problem. And Denmark, with the wind power too much, you have a frequency problem. It might be a more clear business case for that one when it comes to other countries*."

R82, an industry actor, believed that the increased complexity of V2G would result in a very poor business case, and thus they preferred a simpler, cheaper centralized battery solution:

"*We think there is a very poor business case behind this if you think about the investment in the hardware and the benefit for society, so to be honest, we believe that there will be more centralized fast charging stations like you have a gasoline stations today, and … in that station there can be a centralized battery installed*."

Finally, R99 believed that V2G would not be cost effective as a result of the additional inverter, and believed that while it's an interesting idea, no one had really calculated the costs and the benefits:

"*That the [additional] cost would be prohibitively high, probably, and you know all the chargers, all the … what do you call it, the AC/DC thing in the car needs to be more expensive, and all these … you know, honestly I don't think anyone's really done the math. And thought it through. But it's an interesting dream.*"

On the other hand, R72 believed that there were sufficient revenues to develop a business case, but pointed to a variety of barriers, particularly the additional cost of metering, as ruining the business model for V2G:

"*So if you do a little bit of calculation [of the additional cost of meters], that's not good for the business case. And I think that's really one of the main barriers for having V2G*."

Indeed, the lack of business models was often connected to the electricity market structure, which we discuss in the next cluster. In addition to the metering issues that R72 alluded to, another prominent issue was the taxation of electricity both in and out of the battery, known as double taxation. As a result, several experts believed that V2G would not be viable, despite conceding its economic benefits.

The experts believed that the business model impediment was pervasive, and identified four types of impacted actors in their quotes: 1) the potential aggregator implementing V2G bids, 2) OEMs business model incentive to make their EVs V2G capable, 3) for TSOs and DSOs to encourage V2G deployment, and 4) consumer willingness to participate in V2G. In addition, many of these issues were interconnected – as potential aggregators were dependent on OEMS agreeing to make their EVs V2G capable, on friendly regulatory structures in order to participate, and on consumers to agree to allow them to aggregate their EVs.

Likewise, because the benefits of V2G were dispersed among those actors, none had the consolidated business interest to be willing to pay for the investments for V2G. As a result, R103 noted although V2G was a smart idea it was essentially left in a no man's land:

"*[F]rom an energy technical point of view, it makes perfect sense to have vehicle-to-grid, but if you start looking at who's doing the investment, and who will pay for the extra service for it provides, it becomes difficult.*"

Touching upon the consumer acceptance barrier discussed above, R218 noted that because of the battery usage implications, the business case needs to be explicit for consumers to agree to participate:

"*You need to establish business cases, because if someone are to use my battery, I want, I need to have some kind of payment or incentives to make that happen*"

While a V2G system is very likely to include some type of compensation, explicated within a contract with a customer, it is apparent that the experts were skeptical that a V2G model could feasibly be

developed such that customers were offered any payment or incentive. Indeed, as a result of this dispersed interest and benefits, many experts believed that even if V2G had a business case, the business model would take longer to develop. To illustrate, R144 connected V2G to the current lack of capable models, and suggested that both the lack of models and the slow turnover rate would prevent Finland from reaching enough EVs to make the business model of V2G viable:

"*So just having Nissan and Mitsubishi doesn't cover it. And unfortunately in Finland, the average age of vehicle is quite high. So it's a long time before we have to renew the fleet of cars in Finland. So for us to get enough V2G capable cars to make this a business case, I think it won't be in the next 5 years*."

Conversely, and somewhat ironically, some experts believed that the reason there was no business model around V2G was not a lack of initial value, but instead that the market would be flooded rather quickly due to the enormous capacity that an entire fleet of V2G could provide, especially compared to the average frequency regulation market demand. For example, when discussing the future of V2G on the frequency regulation market, R114 noted that if the Danish fleet of personal vehicles were V2G capable its capacity of several gigawatts would vastly outweigh the frequency market capacity, characterizing those overly optimistic about V2G as wrong:

"*They are wrong in the sense that these auxiliary services, for example, frequency regulation - the best part of Denmark in primary server market is only 26 megawatt and secondary reserve is 100 megawatt … They have these people saying this about megawatt regulation have lost their overview about magnitude*."

Either way, the business models need to be clearly defined for a variety of actors and persisted throughout many of the barriers discussed here. Many experts, similar to their perceptions of consumers, believed the concept of V2G as overly complex and costly, both in its technical and regulatory aspects. Equally, the abundance of cheap alternative storage in the Nordics, namely hydro reservoirs, caused many experts to believe the further exploration of V2G would be pointless. On the other hand, some experts believe in the economic value of V2G, but stated that some impediments stood in its way before a full business model could be developed.

3.4. Cluster 4: insufficient EV volume and electricity market structure

Finally, 10% of experts discussed how there would need to be a much larger amount of EVs necessary for V2G participation. Some of the respondents connected this to the business case of V2G (i.e., need more EVs to make a profit), whereas others connected it to a required capacity on the electricity market (either in regulation or just general impact). Experts believed both that there currently are not enough EVs to implement V2G, while other experts were skeptical that they would ever reach the threshold for V2G participation (potentially because of the perception that it would require thousands or millions of EV). For example, R20 dismissed V2G in Iceland overall, as only Reykjavik would have enough vehicles to provide V2G:

"*I don't think it will be possible here. Mostly because of, okay it will only be beneficial in Reykjavik, because there is the only place with a sufficient mass of cars*."

Indeed, R165 viewed the low number of cars as the central barrier to V2G, especially in regards to the development of its business case and proof of concept:

"*I think the barrier is the low number of the cars. It's not economically reasonable to bid this kind of fancy-pancy systems if you have just three cars. So you need to have the whole, you know, in order to build such a proof of concept systems, things like that*."

Likewise, R140 believed that V2G could participate in the market eventually, but was skeptical that it could reach the minimum capacity to bid on various electricity markets:

"*Yes, I think it's the market that … first of all, you have a minimum size for the regulation, frequency regulation a hundred kilowatts is enough, and then for the disturbance reserve it's one megawatt. So you have to have the aggregation of the electric vehicles, and they must be available*."

Even in Norway, which by 2016 passed the milestone of 100,000 EVs, experts believed that there would still not be enough EVs to provide any substantive impact, despite the fact that a modest estimate would put the current EV fleet at 300 MW of potential storage capacity (assuming each car had a 3 kW charger). In spite of this, some Norwegian experts thought it would not be for another decade until there are enough EVs to make an impact on the grid, as R203 describes:

"*And today is too few electrical vehicles to do any important impact. But if we got this penetration of electrical vehicles-, in the national transport plan, then in 2030 we have a lot of electrical vehicles, busses and other vehicles, other transport and then it may have important role if we can use batteries in the cars to not to save, to store electricity*."

Related to the perception of EVs' capacity to impact the electricity market, 10% of experts also discussed the electricity market structure as a barrier to V2G. Of the 22 experts who discussed electricity market structure, over half of these were in context of the taxation scheme. The taxation of electricity impacted V2G in two central ways. First, for those who conceptualized V2G as demand management, electricity tax was seen as removing any differentiation in price between hours. As R105 suggests:

"*Taxes. Because the taxes on electricity in Denmark are so high that fluctuations of electricity cost are eaten up by the tax. So actually, what is necessary to remove the taxes or make the tax fluctuate with the cost of the electricity. You could make it a certain percentage of the price, it would actually, it would make the, what do you call it, the fluctuation actually get better. So if it's a percentage, it would enhance the effect*."

Secondly, taxation also affected V2G in that energy moved in and out of the battery would be double taxed. For example, R84 stated that V2G would not be able to prosper until the regulatory issue of double taxation was resolved:

"*If we start with the tax, V2G won't happen with ancillary services unless there's some solution for this taxation issue. I think some solution can be found, some like hacks and fixes, which are not very pretty and are not very optimal. If you have enough consumption as an aggregator you can have processed power when you don't pay taxes, and that would help you somewhat*."

Likewise, R140 in Finland faced similar impediments when providing electricity market services that required more than just bidding capacity, and suggested that any provision of energy would result in losses of revenues:

"*You are probably are going to lose money because you have to pay the grid fees and you have to pay the electricity tax, so probably only for the electricity that you buy because you sell the electricity for Fingrid, I don't know whether you have to pay electricity tax for that, but then you only get the money for the regulation price for that hour, and that's less than, because you have to pay the grid fees, so every time it's activated, you lose money*."

Beyond taxation, other issues discussed included the lack of a regulatory definition for aggregators, immature market structure, and the grid itself not being smart enough. Of these, the most common was the regulatory framework for independent aggregators, which, as R136 illustrates, posed a conundrum without the existence of clear rules:

"Because of course for example, we want to allow that independent aggregators participating in the market, but we need to have clear

Table 1
Differentiation of V2G Barriers by Country, as shown by percent of interviews in respective country discussing each barrier. The most commonly discussed barrier within each country is bolded to highlight inter-regional disparities.

Barrier	Iceland (n=29)	Sweden (n=42)	Denmark (n=45)	Finland (n=50)	Norway (n=61)	Total (n=227)
Preference for other technologies	24%	**36%**	24%	14%	**38%**	28%
Consumer resistance	0%	22%	9%	**30%**	17%	17%
Poor business case/model	0%	10%	20%	12%	25%	15%
Unnecessary here	**28%**	21%	4%	0%	25%	15%
Uncertainty and skepticism	24%	10%	22%	12%	10%	15%
Increased cost, complexity	0%	10%	**27%**	16%	8%	13%
Battery degradation	0%	17%	18%	18%	7%	12%
Insufficient EV volume	10%	7%	7%	18%	8%	10%
Electricity market structure	0%	2%	7%	12%	5%	10%

rules, what they can do … Because it should at least some markets, they can participate, but can they participate in all market places?"

Unlike the previous three clusters, which all suggested V2G's main challenges were endogenous to the technology, whether it be technical inferiority to other technologies or skepticism of economic benefits, this cluster was more exogenous in its barriers. Thus, for the first three clusters, it was a question of showing, communicating and understanding the benefits of V2G across the plethora of involved actors and users, but here the resolution lied more within the maturity of the EV market to reach enough mass to make V2G viable, and in structural changes in the laws and regulations the govern the electricity market.

3.5. Trends across countries & expertise

As implied through the analysis of the four clusters, there were some geographical and expertise-based differences among the experts' perspectives of barriers. In Table 1, we show how the top nine barriers were distributed among the five Nordic countries, noting that there are some notable distinctions within certain countries. For example, in Iceland substantially more experts believed that V2G was unnecessary and they expressed uncertainty and skepticism about the technology. As a result, none of the Icelandic experts discussed other V2G barriers, such as consumer resistance and business cases, presumably because they viewed the barriers to V2G to be more primary and insurmountable.

Another interesting trend, albeit intuitive, is that Danish and Finnish experts discussed V2G the least in terms of it being unnecessary in their local contexts, which is sensible considering their comparative lack of hydro reservoirs. On the other hand, despite the apparent need for local storage, Danish and Finnish experts expressed the second and third most (after Iceland) uncertainty and skepticism towards V2G technology. Thus, even in countries where storage is needed the most and V2G has made the most technical and commercial progress, skepticism over the technology remains a primary barrier from the perspective of experts. In other words, for V2G to diffuse in areas where it makes the most sense to, basic elements of the system need to be demonstrated to experts, and most likely, to other actors in the socio-technical system. In this thread, consumer resistance was most discussed in Finland and Sweden, possibly because the other countries have greater experience with EVs (Norway) or with V2G (Denmark). On the other hand, there may be cultural differences, particularly in Finland, where consumers were often characterized as conservative and risk-averse. Certainly, the potential benefits and viability of V2G need to be shown to both experts and consumers.

The remaining trends found in Table 1 are likewise more intuitive. For example, preference for other technologies is relatively consistent throughout the five countries, but pronounced in countries with substantial hydro capacities. Battery degradation and the increased cost/complexity of V2G were both mostly consistent, though interestingly, it was discussed less in Norway than other countries, possibly due to increased EV familiarity and reduced range anxiety (Franke and Krems, 2013). Lastly, the poor business case/model was more or less evenly discussed across the Nordics (outside of Iceland, for the reasons proposed above).

In addition to trends across countries, we also investigated how the interviewee's expertise moderated their discussion in Table 2. Though some of the disparities are due to smaller sample sizes (e.g. the 0% of Funding/Investor experts discussing consumer resistance), there are several notable trends. First and foremost, the most obvious difference is that Energy and Electricity experts preferred other technologies the most, presumably due to familiarity with the other storage sources (e.g., hydroelectric or hydrogen). Similarly, Transport experts believed that other technologies did not pose such a challenge, perhaps due to the fact that EVs (and thus, potentially V2G) would come into place due to transportation-related decarbonization anyway, or perhaps due to ignorance of other electricity storage sources. Nonetheless, discussion of the barriers in the Transport field were the most pluralistic, without a single barrier being discussed substantially more than any other (though consumer resistance was slightly common than others).

Most concerning for the diffusion of V2G is that the experts within the Funding and Investing field were the most skeptical and uncertain about the technology. This could be a result of investors tending to be more wary of risks, but a clear implication for V2G to move beyond pilot projects to large-scale commercialization is assuring investors that the system is viable and provides clear benefits. Likewise, the increased cost/complexity and poor business case/model barriers were both discussed the most frequently by interviewees working within the EV and EVSE industry. Presuming that EV and EVSE actors are the most likely to be among the leaders in a transition to V2G, there should be more focus on pilot projects demonstrating the cost-effectiveness of adding V2G to an EV, and the viability of their business model. As this is arguably already underway (Sovacool et al., 2018b), there needs to be better communication of current successes in V2G to other EV and EVSE industry actors.

Another interesting note is that experts with a focus on the environment and climate change tended not to discuss many of the other common barriers, and instead focused more on the structure of the electricity market, above even those working with the electricity field. Arguably, this could be a result of their frustration with the lack of environmental considerations in current electricity market structures, in particular the undervaluation of externalities from fossil-fueled electricity market actors. Similarly, the most pertinent barrier for

Table 2
Differentiation of V2G Barriers by Expertise, as shown by percent of interviews discussing each barrier. The most commonly discussed barrier within each expertise is bolded to highlight certain inter-field disparities.

Barrier	Transport, City Planning (n=73)	Energy, Electricity (n=63)	Funding, Investor (n=10)	Enviro, Climate Change (n=12)	Vehicle Researcher (e.g. fuel efficiency) (n=22)	EV, EVSE Industry (n=34)	Other (n=13)	Total (n=227)
Preference for other technologies	11%	**51%**	**40%**	17%	**27%**	**29%**	8%	28%
Consumer resistance	**16%**	24%	0%	8%	5%	18%	**23%**	17%
Poor business case/model	11%	21%	10%	0%	14%	26%	0%	15%
Unnecessary here	8%	19%	20%	0%	14%	26%	15%	15%
Uncertainty and skepticism	11%	22%	30%	8%	9%	9%	15%	15%
Increased cost, complexity	14%	16%	0%	0%	5%	24%	0%	13%
Battery degradation	10%	13%	0%	8%	**27%**	15%	8%	12%
Insufficient EV volume	12%	6%	20%	8%	5%	12%	15%	10%
Electricity market structure	7%	16%	0%	**25%**	5%	9%	0%	10%

vehicle researchers was the potential battery degradation that could result from V2G, understandably due to their sensitivity to an EV's range, especially as it already is perceived as inferior to conventional vehicles. In sum, though there are some exceptions, the most common barriers across the fields of expertise focused on the uncertainty and skepticism of V2G's benefits, commercial viability, and competitive advantage.

4. Conclusion & implications

Throughout the paper, there was an uncertainty about V2G in a multitude of respects, as experts were uncertain about its technical viability, technological performance, and its benefits. Though the literature presents V2G as having moderate to substantial benefits (Sovacool et al., 2017), and some Nordic experts espoused a plethora of V2G benefits (Noel et al., 2018), many Nordic experts were generally skeptical. Indeed, despite the wide variety of papers published in the field of V2G and the promise that the technology could provide, it is perhaps striking that so many experts were uncertain of its benefits or the even viability of its operation. This perhaps indicates that there has been a disconnect between the literature and the different industrial and sector actors that eventually would push V2G into commercial phases; reflecting that V2G technology is still an emerging concept with a lack of pilot projects across the Nordic region, other than in Denmark. Consequently, it is clear that one implication of this research is that the benefits of V2G need to be better communicated to experts throughout the transport and electricity sectors. Nonetheless, the prevalence of hydropower throughout the Nordics hints that V2G may firstly need to go where the benefits are more prevalent in order to capture the largest benefits and provide proof of concept.

Indeed, while we presented the top nine barriers in the manuscript above, the remaining 26 barriers presented in Fig. 1 above also warrant investigation (especially if more major barriers are resolved). Many of these barriers underscore our conclusions about expert uncertainty and skepticism towards V2G. For example, several of these barriers reinforced the idea that V2G requires proof of concept, such as the Aggregation/Coordination, Immature Technology, and Actor knowledge/motivation barriers. Secondly, another common theme includes various challenges in the electricity market structure, both in general (Laws/Regulations, Conservative DSOs) or specific concerns (Metering issues, Hourly, Pricing, Net Metering). Beyond these thematic concerns, there are other barriers that may warrant further research in the future. The willingness of OEMs to convert their EVs to be V2G-capable for example, poses an obvious challenge to V2G diffusion and is a barrier that has not been thoroughly explored. Secondly, the consumer's perception of freedom and the extra planning required to do V2G also poses an additional social challenge, though it may be too early in the diffusion process of V2G to gauge such concerns.

Beyond experts, our results corroborate that consumer acceptance may be a key challenge to the implementation of V2G. That said, recent research has implied that the largest concern to consumers, battery degradation due to V2G participation, may be minimal (Wang et al., 2016). While battery degradation as a result of V2G is still a novel topic, the results of these recent studies imply that it is a non-issue, and this needs to be properly communicated to EV users and also to experts for implementation of V2G. Similarly, reducing the complexity of V2G for consumers may be an important driver in the acceptance of V2G. Thus, future research should focus on how to simplify the complexities of V2G electricity market participation for the consumers in the most efficient manner.

Likewise, other future research should focus on examining the other clusters described above. For example, many experts were uncertain of the business model of V2G, more work should be done to show that the potential economic value of V2G (Sovacool et al., 2017; Kempton and Tomić, 2005a) can be converted into a practical business model. To the authors' knowledge, only one previous study has investigated the business model of V2G, but focused only on a parking garage operator (Brandt et al., 2011). Future research should be expanded to other case

studies, as well as compare and contrast other competing forms of technology, such as stationary batteries.

Finally, the electricity market structure provided a clear exogenous barrier that policymakers and future researchers can focus on. Particularly, it is clear that in the Nordics that electricity taxation is not optimal to the development of V2G, and thus should be reconfigured to prevent double taxation while concomitantly providing clear rules for independent aggregators. In addition, future researchers may elect to focus on assisting policymakers with ideal manners to restructure electricity grids.

Ultimately, though, we find that V2G, despite all of its promise, currently occupies a treacherous middle ground where it is still subject to expert scrutiny coupled with consumer mistrust. Given that the two certainly interact, and feed into each other, it is all but certain that V2G will remain perpetually sidelined in the Nordic region until at least experts or potential consumers overcome one of these barriers, ideally both. This serves as a stark reminder than new innovations, no matter how net beneficial they may be, must overcome cognitive and perceptual barriers alongside the more established, and rigorously examined, technical and economic ones.

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Appendix I. Overview of Semi-Structured Research Interviews

Table A.1
Overview of Semi-Structured Research Interviews

Country (5)	Cities (17)	Interviews (227)	Visit (9 months)
Iceland (n = 29)	Reykjavik	1-22, 29	Sept/Oct 2016
	Akureyri	23–28	Sept/Oct 2016
Sweden (n = 42)	Stockholm	30-43, 66–68, 70	Nov 2016
	Gothenburg	44–61	Nov 2016
	Lund and Malmo	62-65, 69, 71	Nov 2016
Denmark (n = 45)	Other*	72	Jan 2017
	Greater Copenhagen Region	73-100, 113, 115	Jan/Feb/Mar 2017
	Aarhus	101-102, 104-107	Feb 2017
	Other*	103	Feb 2017
	Aalborg	108-112, 114, 116	Feb/Mar 2017
Finland (n = 50)	Greater Helsinki region	117-144, 154, 163	Mar 2017
	Tampere	145-153, 155, 164	Mar 2017
	Oulu	156-162, 165-166	Mar 2017
Norway (n = 61)	Greater Oslo region	167–208	Apr 2017
	Trondheim	209-220, 222	May 2017
	Tromsø	221, 223-227	May 2017

*Two Danish towns are not mentioned by name for anonymity of interviewees.

Table A.2
Summary of Experts Participants

Classifications	Interviews (n = 227)	Respondents (n = 257)	% of Respondents
Country = Iceland (Sept–Oct 2016)	29	36	14.0%
Country = Sweden (Nov–Dec 2016)	42	44	17.1%
Country = Denmark (Jan–Mar 2017)	45	53	20.6%
Country = Finland (Mar 2017)	50	57	22.2%
Country = Norway (Apr–May 2017)	61	67	26.1%
Gender = Male	160	207	80,5%
Gender = Female	40	50	19.5%
Gender = Group	27		
Focus = Transport or Logistics	73	81	31.5%
Focus = Energy or Electricity System	63	75	29.2%
Focus = Funding or Investment	10	12	4.7%
Focus = Environment or Climate Change	12	16	6.2%
Focus = Fuel Consumption and Technology	22	23	8.9%
Focus = Other	13	14	5.4%
Focus = EVs and Charging Technology	34	36	14.0%
Sector = Commercial	68	70	27.2%
Sector = Public	37	46	17.9%
Sector = Semi-Public	40	51	19.8%
Sector = Research	37	39	15.2%
Sector = Non-Profit and Media	12	13	5.1%
Sector = Lobby	23	25	9.7%
Sector = Consultancy	10	10	

(continued on next page)

Table A.2 (*continued*)

Classifications	Interviews (n = 227)	Respondents (n = 257)	% of Respondents
			3.9%

Source: Authors. Focus represents the primary focus area of the organization or person in question, sector represents the sector the company was working in (semi-public referring to commercial companies owned by public authorities, like DSOs).

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